REVIEW ARTICLE

A Conceptual Review of Electrical Power Generation Processes

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ABSTRACT: The article presents a conceptual overview of power generation systems. Electricity is probably the most versatile energy carrier in modern economies and is therefore fundamentally linked to human and economic development. Therefore, electricity deserves special attention due to its contribution to global greenhouse gas emissions, which is reflected in the continuous development of low-emission power generation technologies. The main objective of this overview of power generation technologies is to provide more technical information than usual in global assessments and to capture the latest insights from the literature. This work reports technologies such as: hydroelectric, nuclear, wind, photovoltaic, concentrated solar, geothermal, and biomass. This selection is quite representative of technologies that are important in terms of their potential contribution to a global carbon economy. In addition, the combination of conventional energy with other sources, in particular renewable energy sources, is examined. This report systematically examines the literature on the energy sources and renewable energy potential, resulting in an overview of the potentials.

KEYWORDS: Power Generation; energy availability; greenhouse gases; fossil fuel; renewable energy sources.

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1. INTRODUCTION

Globally, energy availability is an important indicator of industrialization, economic growth, and sustainable development. Its demand is determined by the human aspiration to sustain and improve ourselves, our families and our communities; and with an estimated seven billion people on earth coupled with continuing population growth, energy demand is expected to widen. Efforts to match this increasing population and economic development with adequate energy supply in many countries have resulted in serious implications for the environment because energy generation processes emit pollutants, many of which are harmful to the ecosystem. In fact, the burning of fossil fuel results in the emission of large amounts of greenhouse gases, particularly carbon dioxide [1].

Following this trend, the past decades have witnessed tremendous advancement in energy conversion processes to meet up with the ever-increasing energy needs in industrial and residential circles. Most often, the common energy conversion method has been the burning of fossil fuel which accounts for a large proportion of generation methods [2]. While efforts to meet up with energy needs are commendable, it is appropriate to balance the trade-off between energy efficiency and environmental sustainability. Recently, the long-term hazards of continuous carbon dioxide emissions to the atmosphere were highlighted in the media and published literature [3-6].Remarkably, research and technology are presenting alternative energy sources and utilization of waste energy, especially from energy conversion plants.

In Nigeria, for example, the energy framework is constituted from the burning of fossil fuels in power plants which have been unsteady and inadequate for the teeming population. Appropriate electric energy production and consumption have become the preoccupation of the government because of the constraints it poses to industrial capacity utilization and employment creation opportunities. This is most protracted in the rural areas where lack of access has stifled the local economy and stunted

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the growth of small businesses and industries, which under ideal conditions should have served as a significant source of employment and rural income. In the urban areas of Nigeria, experiences over the years show that the erratic and epileptic power supply has severely disrupted economic expansion leading to the closure of businesses which cannot sustain the huge cost of maintaining private electric generating plants, with associated job losses. The Nigerian experience underscores the importance of electricity for economic growth especially for a developing country and the overriding importance of enhancing the operations of the electric power industries if it is to effectively underpin the economic development process [7].Therefore, the present study reviews comparatively the economic and environmental assessment of the use of various energy sources for power generation.

2. CONVENTIONAL ENERGY GENERATION - THERMAL POWER PLANTS

Thermal power plants, especially gas turbine plants, are in large numbers and account for about 69.34 % of total installed electricity generation capacity worldwide [2]. However, due to environmental concerns, there is the need to reduce the proliferation of conventional thermal power plants due to their pollution potential [8]. This has resulted in the development of technologies that use renewable energy sources and measures to reduce the emission of harmful substances into the atmosphere [9]. The new challenge to flood the energy market with environmentally-friendly systems as he stated, are decisive impulse for introducing changes in power plants and combined heat and power plants. This as well, helps in the implementation and continuous development of new technologies which would allow for the electricity and heat production to be utilized in the least harmful way to the environment [9]. In recent years, much research has been devoted to reducing pollutant emissions and optimizes the performance of thermal power plants. Such studies are reported across different thermal power plants shown in the following sections.

2.1 Coal fired plants

More than one third of the world's electricity is generated by coal-fired power stations [10]. However, these plants are not environmentally friendly as they continue to cause hundreds of thousands of early deaths each year, from air pollution [11]. These plants emit over 10 Gt of carbon dioxide each year, constituting almost one fifth of the total emissions, thereby remaining the single largest source of the greenhouse gases which is causing global warming [12]. At present, there is a growing reduction in the use of coal fired plants coal stations in Europe and America while some are still built in Asia [13]. The various factors which affect power generation from other energy carriers are similar to an extent with respect to thermodynamics and economics. For instance, Kumar et al.,[14] investigated the impact of various factors affecting a coal-fired power plant economics for electricity generation in India, while Li et al., [15] presented the thermodynamic optimization of a double reheat system in ultra-supercritical coal power plants.
In addition to thermal plants application in the use of coal, other subsidiary cycles can be co-powered with it. One of such example is the Kalina cycle where computer simulations can be provided with a coal fired steam power plant [16]. In the area of optimization, the effective parameters which govern the overall improved performance of coal powered plants have been performed using different tools. For instance, Suresh *et al.* [17] examined an ANN and GA based optimization of a high ash coal-fired supercritical power plant. They revealed that a reduction of about 42 % in fuel consumption using coal with 16% of ash compared with the coal having 49 % ash. Adibh at la., and Kaushik [18] performed an energetic and exergetic analysis of a coal fired supercritical thermal power plant at 60, 80, and 100 percent of normal continuous rating conditions under constant pressure and pure sliding pressure operation. They indicated that the maximum rate of exergy destruction was encountered in the boiler than any other component in the power plant, and is closely followed by the turbine.

Yang et al.,[19] applied conventional and advanced exergy analysis in a large coal-fired power plant at ultra-supercritical parameters. They revealed that with an increase in the steam conditions, the exergy destruction ratio of the boiler was significantly reduced, contributing mainly to the system improvement. Xiong et al., [20] simulated and analyzed an oxy-combustion pulverized-coal-fired power plant using Aspen Plus. The simulation results revealed that the carbon dioxide concentration in the flue gas from the boiler can be more than 80% and the purity of

the carbon dioxide product from flue gas treatment unit can reach 99%. Wang *et al.,* [21] studied a pulverized coal-fired power plant to explore the exergy destruction and the pollutant emissions characteristics of the plant. The results suggests that the volume of sulphur dioxide concentration of flue gas in flue gas desulphurization unit outlet is relevant with the plant output work and the sulphur fraction of coal; and the latter factor performed the key role in emission concentration. Furthermore, Wang et al.,[22] investigated the optimal design of large-scale coal-fired power plants from the perspectives of thermodynamics and economics. They demonstrated that there is an efficiency gap of over 2 % points between the real design and the thermo economically optimal designs. Additionally, any reduction of the cost of electricity depends relatively on the temperature factors in the cost function of the steam generator. Also, Restrepo et al.,[23] performed an exergetic and environmental analysis of a typical Brazilian pulverised coal power plant. Their findings indicate that up to 1300 kg/MWh of carbon dioxide emissions estimated by the environmental model was emitted by the plant; with the highest impact associated with the power plant, and accounts for 1140 kg carbon dioxide emissions equivalent.

2.2 Biomass based energy conversion systems

Biomass, being the second largest source of renewable energy has a wide range of resources potentially available for conversion (REN21) [24].This consists of waste and residues from agriculture, biodegradable fraction of products, forestry and related industries, and biodegradable fraction of industrial and municipal waste. At present, there are various technologies to convert biomass resources into higher-value products like liquid and gaseous fuels and chemical products through thermochemical, biochemical or chemical means [25,26]. In literature, several research works on biomass conversion for energy generation as well as the thermoeconomic evaluation are reported. Liu et al., [27] presented the thermodynamic modelling studies of a biomass-fired CHP system with an ORC. They showed that the ORC efficiency depends not only on the operating parameters but also on the ORC working fluid. Furthermore, the results also indicate that both superheating and sub-cooling were not favorable to the ORC efficiency.

Yushiet al., [28] developed a chemical equilibrium model to predict the product composition of a biomass gasification system using superheated air and steam. Their results showed that the chemical energy efficiency of the produced syngas is highest when the ratio of water vapor to biomass is 1.83. The determined maximum values for energy efficiency and exergy were 81.5 % and 76.2 %, respectively.
Soltani et al., [29] developed three biomass-based systems for electricity generation. They demonstrated the feasibility of using biomass syngas for power generation in combustion turbines. Several other configurations of biomass-based post fired combustion turbines are reported in literature [30,31]. Similarly, Khorshidiet al.,[32] investigated different configurations for auxiliary units to provide the energy required for a carbon dioxide capture from an existing coal power plant. The results indicate that using a biomass auxiliary unit to provide the energy required for capture in a coal plant while venting the emissions from the auxiliary biomass unit to the atmosphere, lead to almost the same emission intensity. Datta et al., [33] performed a thermodynamic analysis for an externally fired gas turbine cycle with an integrated biomass gasifier. They showed that the thermal efficiency of the cycle was within 16 to 34 % for the range of operating parameters under investigation.

2.3 Gas fired plants

Gas fired power plants are in large numbers and account for about 69.34% of total installed electricity generation capacity worldwide [2]. Consequently, there has been an in-depth theoretical analysis on performance enhancement using energy and exergy models. Chen *et al.* [34] established a combined cooling, heating and power (CCHP) plant model composed of an irreversible closed Brayton cycle and an endo reversible four-heat-reservoir absorption refrigeration cycle using finite time thermodynamics. They showed that there exist two exclusive groups of the seven optimal heat conductance distributions and optimal compressor pressure ratios, which lead to the maximum dimensionless exergy output rate and maximum exergy efficiency, respectively. Boyaghchi and Molaie [35] used the advanced exergy analysis method to investigate the sensitivity of the different parts of exergy destruction and performance of an

actual combined cycle power plant. They revealed that the value of endogenous unavoidable exergy destruction of all components decreases with increasing turbine inlet temperature except low pressure steam turbine, high pressure evaporator, high pressure super heater and air compressor. Also, increase of compression ratio, as they held, brought about decrement in endogenous unavoidable exergy destruction of all components except the air compressor and gas turbine.

Bolatturk et al., [36] conducted an exergy and thermoeconomic analyses of Turkey-based Cayırhan thermal power plant. They disclosed that the thermal and second law efficiencies of the power plant were found to be 38 and 53%, respectively. Chen et al., [37] presented the off design performance analysis of a combined cooling, heating, and power system. Their results show the combined cooling, heating, and power system could save energy when the power output of the gas turbine is above 30 % of the full load. Anozie and Odejobi [38] investigated the influence of reference temperature on exergy and exergoeconomic performance parameters of a thermal plant. They revealed that an increase in the ambient temperature from 15 to 35°C, caused an exergy efficiency decrease from 11.7 to 11.5% and irreversibility increase from 1790 MW to 1812 MW. Ahmadi and Dincer [39] performed an optimization as well as the thermodynamic and exergoeconomic modelling of a gas turbine power plant. After optimization, their results demonstrated a 50.50 % reduction in environmental impacts. Ahmadi and Dincer [40] revised a combined cycle power plant with a supplementary firing system through energy and exergy analysis. Their results showed that the average difference between the model results and the actual data was about 1.41 %. Similarly, Kumari and Sanjay [74] analyzed the effect of various cycle operating parameters on thermodynamic and emission performance of the basic gas turbine and the intercooled gas turbine cycles on a comparative basis. They revealed that the rational efficiency of the intercooled gas turbine was about 8.39 % higher than the basic gas turbine plant.

2.4 Combined cycle power generation systems

Combined cycle power plants (CCPPs), represent processes which culminate in the production of unique commodities in an integrated fashion, including the use of expanded gas stream in a heat recovery steam generator (HRSG) for electricity generation in a steam turbine. In the arrangement for its implementation in the present work, the exiting gas stream to the atmosphere was reheated with biomass to capture the carbon dioxide emissions. A survey of the recent developments in literature on CCPPs is presented.

Tiwari et al.,[41] presented an exergy analysis of a CCPP. They showed that more exergy losses were encountered in the gas turbine combustion chamber reaching a magnitude of 35 % of the total exergy losses. Abuelnuora et al., [42] performed an exergy analysis of a CCPP using the second law of thermodynamics. They verified that the main sources of exergy destruction were in the combustion chamber due to their high irreversibility. Adibhatla and Kaushik [18] performed energy, exergy and economic analyses of a conceptual power plant cycle resented in Figure 1, formed by adding solar energy in steam cycle of a natural gas-based combined cycle power plant. They disclosed that the energy and exergy efficiencies of solar field were 53.79 and 27.39 % respectively. Balku [43] developed a model for a combined gas-vapour power system using mass, energy, entropy, and exergy balances to determine the most important parameters which influenced the efficiency of such plants. Their result showed that the exergy destruction decreased by 22.65 %.

Ersayin and Ozgener [44] presented a performance analysis of an operating power plant using real operating data acquired from the power plant control unit. Both energy and exergy efficiencies of the combined cycle power plant were found to be 56 and 50.04 % respectively.

Manente [45] built a detailed off-design model (Figure 2) of a three pressure level natural gas CCPP to assess the different integration schemes of solar energy which kept the equipment of the combined cycle unchanged or included new equipment that comprised the steam turbine and heat recovery steam generator. From the evaluation, it was demonstrated that without modifications to the existing equipment, the maximum incremental power output from solar at design solar irradiance was limited to 19 MW.

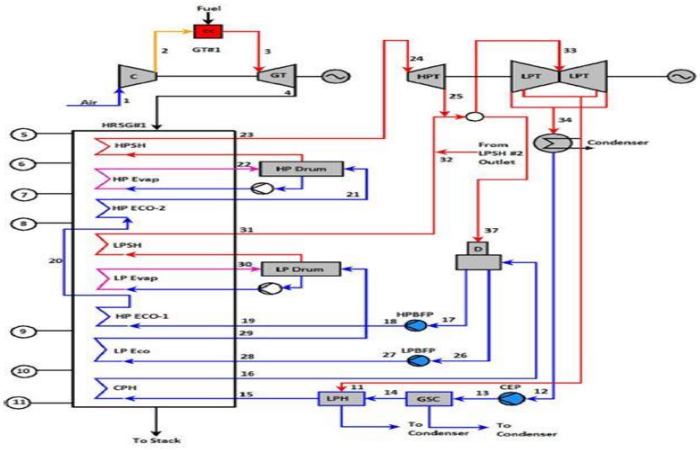

Figure 1: Integrated solar direct steam generation combined cycle power plant [18]

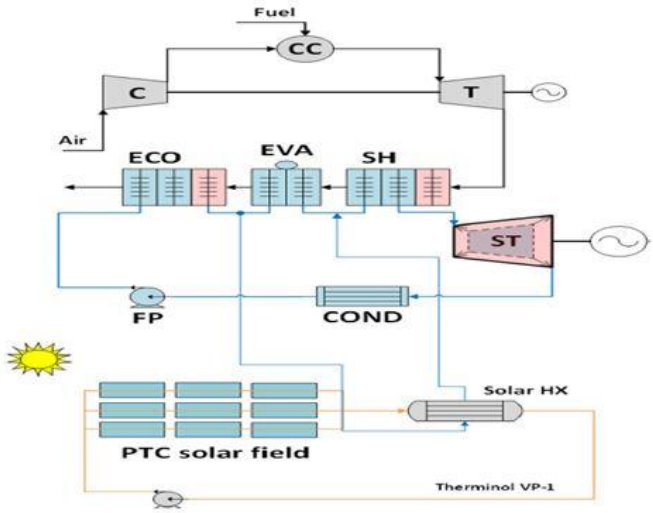

Figure 2: Schematic of integrated solar combined cycle [45]

Oko and Njoku [46] explored the thermodynamic feasibility of retrofitting an existing 650 MW combined thermal power plant by including an organic Rankine cycle unit (Figure 3). For additional power generation in an organic Rankine cycle, they revealed that low temperature exhaust heat from the flue gases exiting the combined cycle power plant can be used resulting in increased overall plant efficiency, power output, and in environmental impact.

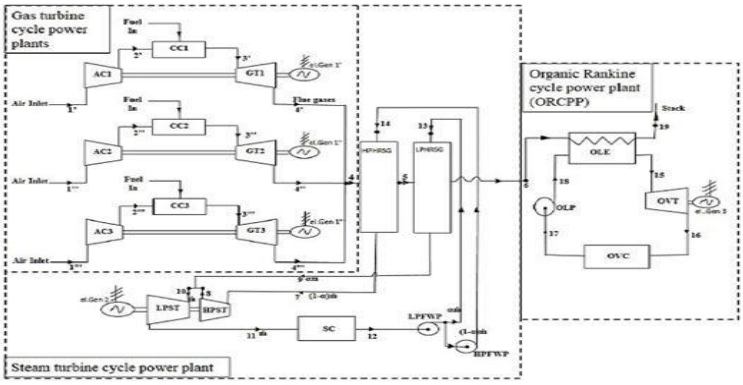

Figure 3: Schematic diagram of an integrated gas-, steam-, and organic fluid-turbine cycle power plant [46]

Sanjay and Bishwa [47] performed an energy analysis of an intercooled combustion turbine based combined cycle power plant by the selection of a suitable intercooling pressure ratio. By the selection of low-intercooling pressure ratio of 2.5 and intercooling pressure ratio of 4, with compressor pressure ratio of 36, they indicated enhanced system performance. Yuanyuan and Yongping [48] presented a thermodynamic and economic analysis for an integrated solar combined cycle (ISCC) system with two pressure levels DSG solar fields (ISCC–2DSG) as presented in (Figure 4). They revealed that the capacity factor increased due to greater electricity productionfor ISCC–2DSG systems without thermal storage.

Bakhshmand et al.,[49] investigated the exergoeconomic analysis and optimization of a triple-pressure combined cycle power plant with one reheat stage (Figure 5). They indicated that the optimization process brought an increase of about 3 % in energetic and exergetic efficiencies and a reduction of about 9 % in the total thermoeconomic cost.

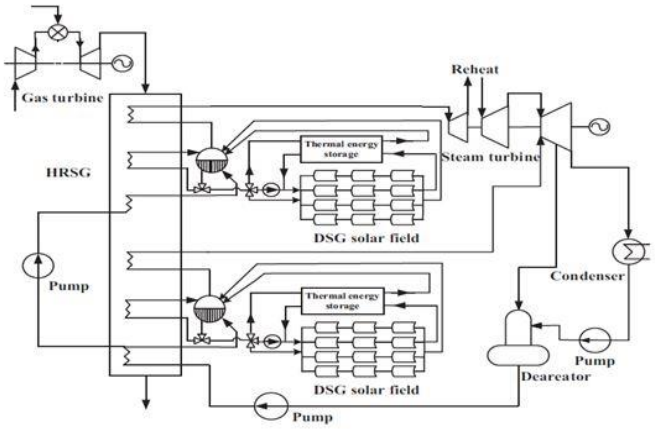

Figure 4: Schematic diagram of an ISCC system with two DSG solar fields with thermal storage [48]

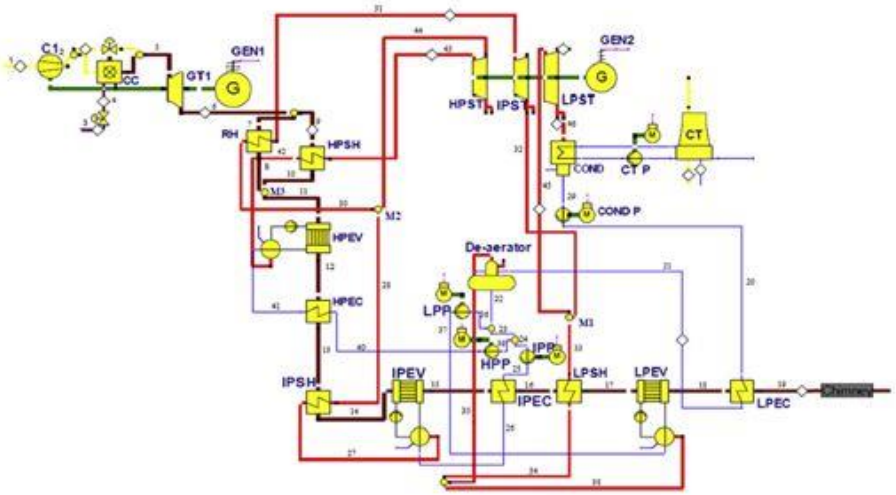

Figure 5: Schematic diagram of combined power plant with triple-pressure levels and one reheating stage [49]

2.5 Geothermal based energy generation systems

Power generation systems which require geothermal energy sources need special attention in their design and operation. In recent times, several researches have provided in-depth analyses of these energy systems in their different configurations. Rudiyanto et al, [50] performed ambient temperature optimization and exergy analysis of the Kamojang geothermal power plant. They disclosed that the system has a total efficiency of 35.86% which allows only 111,138.92 kW electrical power to be extracted from 309,000

kW thermal power being produced by 10 production wells of Kamojang. Makhanlall et al., [51] applied exergy-topological analysis to a binary medium-grade geothermal power plant. They showed that the power plant can operate at high thermodynamic efficiency. Koroneoset al., [52] used data from an experimental geothermal drill to estimate the maximum available work and the efficiency of a potential power plant. They revealed that the system exergetic efficiency can be as high as 41% supportive of the technical feasibility of the proposed geothermal plant. Keçebas and Gokgedik [53] performed both conventional and advanced exergy analyses of an existing geothermal binary power system for power generation (Figure 6). The advanced exergy analysis results were found to be more realistic than the conventional exergy analysis. Budisulistyo and Krumdieck [54] presented a pre-feasibility design investigation for a binary geothermal power plant using a typical geothermal resource located in New Zealand. Results from the thermodynamic analysis revealed that the net electrical power output of the cycle design attained a maximum level at a certain optimum turbine inlet pressure and mass flow rate of the working fluid.

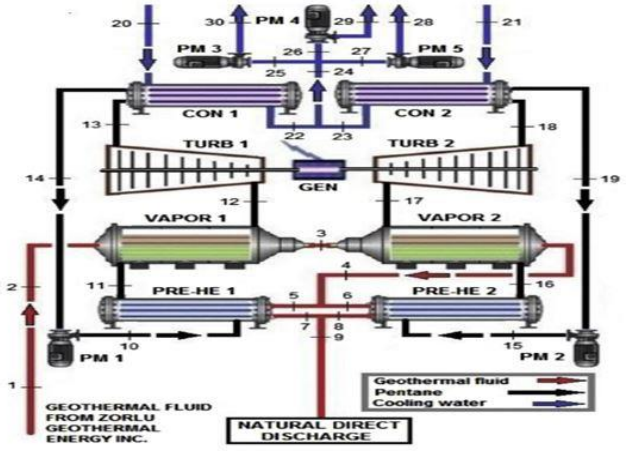

Figure 6: Geothermal binary power system for power generation [53]

Ganjehsarabi et al., [55] modelled a binary geothermal power plant in Turkey. Their results indicated the overall energetic and exergetic efficiencies of the plant were 10.7 and 29.6 %, respectively which were quite small due to the large exergy destruction rate in brine reinjection at 10.3 MW.

3 ELECTRICITY GENERATION FROM RENEWABLE ENERGY SOURCES

In many parts of the world, energy needs have increased significantly due to increasing population, industrialization, technology and economic development. To meet up with this ever-increasing surge for energy demand, numerous energy conversion processes have been proposed and implemented including the burning of fossil fuels in gas turbine plants, steam plants, cogeneration plants, and recently, the use of nuclear and renewable energy sources. Adjustments have been made on existing turbine plants to increase their efficiency and augment net power output. In the category of gas and steam turbines, these adjustments include the development of the combined cycle power plants (CCPPs), which comes in an avalanche of configurations. However, these changes as well as the parent plants constitute huge emission mantra to environmental degradation due to the formation of carbon dioxide emissions. The results have been the proliferation in ecosystem depletion, a trend which poses serious environmental hazards. Interestingly, in recent times, attention has been on singular renewable energy sources [56,57] with a measure of success in its application. In fact, worldwide, about 19 % of the energy generation is from renewable energy. The renewable energy accounted for about 11.8% of total electricity generation in Nigeria by 2010 [58].

3.1 Wind based renewable energy assessment

Nigeria remains without a reliable supply of electricity and lags behind most other developing nations in terms of grid-based electricity consumption. The World Bank estimates that about 56 percent of the Nigeria's 185 million people are off the national grid and

those who are connected to the grid experience incessant power outages and interruptions. This situation is forcing many Nigerians to either look for alternative sources of energy or rely on self-power generation.

Using wind energy to generate electricity is becoming one of the most attractive sources of renewable energy in the world due to the advantage of being a clean, sustainable and ecological friendly energy source [59]. The rate at which conventional energy resources are depleting as a result of exploration is high. Consequently, many countries today have re-directed efforts towards harnessing alternative energy resources, such as solar, hydropower, geothermal, wind power and biomass [60]. Some proposals of wind energy assessment in different parts of the country are presented.

Ajayi [61] has critically examined the prospects and challenges of harnessing wind resources for energy generation in Nigeria. Various government and research initiatives have been reviewed and it has been found that the country has enormous potential for harnessing wind for power generation. The northern states, mountain regions and various locations in the central and south-eastern states have been identified as good wind power areas, with coastal areas stretching from Lagos through Ondo, Ogun and Cross-Rivers to the river states along the Atlantic Ocean in the south–south.

Ohunakinet al., [62] examined the wind potential of Jos, Nigeria using 37 years of wind speed data (1971–2007) measured at 10 m elevation and subjected to a two-parameter Weibull analysis. The results showed that Jos belongs to class 7 of the international wind classification system by recording annual values of mean wind speed, average power density and energy of 8.6 m/s, 458 W/m^2 and 4013 kWh/m^2 /year respectively.

Fagbenle et al., [63] assessed the wind energy potential of Maiduguri and Potiskum. Maiduguri was found to be the better of the sites in terms of monthly and seasonal variation of mean wind speed, but they both can be suitable for stand-alone and medium scale wind power generation.

Mas'udet al., [64] presented the latest evaluation of the renewable energy progress made by both Nigeria and Cameroon. The study showed that these two neighbouring African countries have huge renewable energy potential that have not been developed.

Wind assessment has also been performed in other parts of the world. İlkiliç, [65] investigated the potential of wind energy and assessment of wind energy systems in Turkey. The latest applications have shown that wind energy sources in Turkey are a promising alternative energy.

3.2 Biomass based renewable energy assessment

Biomass refers to various materials obtained from plants and animals that can be used for the formation of useful energy in different forms and purposes [66]. As shown in Figure 7 world over, biomass is the third largest energy resource [67]. Several types of biomass exist such as fibre biomass, organic fertilizer biomass, chemical biomass etc. A biomass by-product, if not managed properly, can have serious impacts on public health, social and environmental issues. Currently, Nigeria is blessed with great biomass resources such as agricultural crops, charcoal, wood, shrubs, forestry waste, grasses, community and manufacturing activities, and aquatic biomass[68]. Nigeria's biomass resources are predicted at 8 102 MJ [69]. Fuelwood is used by many Nigerians for cooking, heating and other house hold purposes especially the rural dwellers. There is great potential in Nigeria's diverse biomass resources that can be transformed into technologies that can help citizens. Nigeria is ranked high in the production of energy crops such as palm oil, cassava, sesame and soybean which can be used for biofuel. According to Abila, [66], Nigeria has the capacity to be a leading biofuel exporter, and that the adoption of biofuel in the country can ease the financial strain and burden on fossil fuel subsidies and also enhance the local source revenue. Due to huge population of Nigeria, municipal solid waste can be useful as cellulosic material for biogas production.

3.3 Solar based renewable energy assessment

There is much variation in solar radiation across Nigeria, but it is higher in the northwest and north-eastern part of the country. However, Nigeria has adequate solar radiation that can generate electricity which can be fed into the national grid, but this has not been utilized (see Figure 8).

The optimal solar radiation in Nigeria is around 7,000 Wh/m^2 in the northern part of the

country and about 4000 W h/m^2 in the southern part of the country per day [70]. Many researchers have been carried out to investigate the solar potentials in Nigeria and almost all of them point to the huge potentials that can be utilized [71,72]. Efforts of harnessing the solar potentials in Nigeria is handled by the Energy Commission of Nigeria (ECN) and is supported by the National Agency for Science and Engineering Infrastructure (NASENI), through three research institutes of ECN.

Akinyele et al., [73] evaluated the life cycle impact (LCI) of a 1.5 kW solar photovoltaic (PV) system. The study provides an insight into the significance and impact of a location's solar energy potential on the environmental performance of a PV system, which can be useful for energy analysis, planning and decision-making purposes.

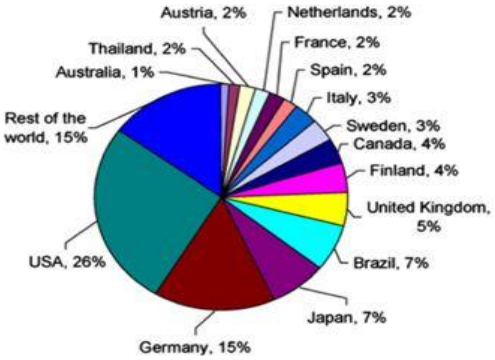

Figure 7: Worldwide distribution of biomass energy utilization in 2008 [67]

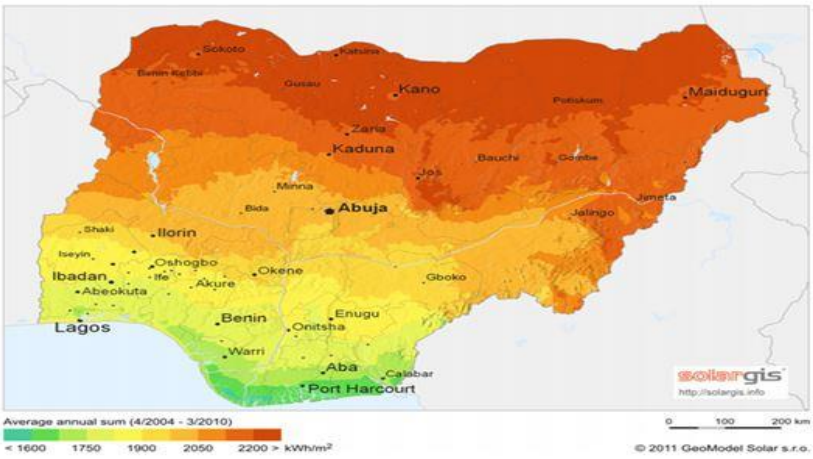

Figure 8: Solar irradiation map of Nigeria [70]

CONCLUSION

The analysed literatures present several possibilities for generating energy. Energy is mainly generated from fossil fuels in gas, steam and hydroelectric power plants, with a small proportion coming from renewable sources. The currently used renewable energy sources are mainly solar and wind energy. The rapid population growth in most African countries have created a significant gap between electricity supply and demand, and its over-reliance on fossil fuels has significant socio-economic, environmental and health impacts. This study examines energy sources and the transition to clean energy, focusing on the potential and uptake of renewable energy. This work have thoroughly reviewed significant number of studies and this report can serve as a guide for energy scientists, the general public and the scientific community.

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